HEALTHY CARRIAGE OF *STAPHYLOCOCCUS AUREUS*: ITS PREVALENCE AND IMPORTANCE[1]

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INTRODUCTION

It seems to have been more than 50 years after *Staphylococcus aureus* had been recognized as a cause of wound infection and other sepsis that its prevalence in normal persons was noted. Thus, no reference to the healthy carrier state appears in the first (1936) edition of Topley and Wilson's *Principles of Bacteriology*, and the flood of papers that have made the subject now so familiar was started in 1937 (30, 34). The earlier neglect of the staphylococcal carrier state was not due to lack of recognition of the healthy carrier state as such, for healthy carriers of typhoid bacilli were well known by 1910, and Glover's work on carriers of meningococci was carried out during World War I. Understanding of the distribution of staphylococci outside septic lesions had to await a satisfactory method for distinguishing the pathogens from the innumerable nonpathogenic staphylococci and micrococci that abound in the environment. This was made possible by the popularization of the coagulase test, in the United States by Chapman in 1934 (12) and in Britain by Cruickshank in 1937 (16). In the following pages, the terms *S. aureus* or simply staphylococcus are used, synonymously with *S. pyogenes*, to refer to coagulase-positive staphylococci.

During the last 20 years, an immense amount of work has been done to define the frequency and significance of the healthy carrier state, and it seems appropriate to review the position reached.

HEALTHY CARRIAGE

Frequency of Carriage in Different Parts of the Body

There have been three studies of the frequency of carriage of *S. aureus* on different skin areas of adults and, although the skin sites included in the surveys were not identical, the results were broadly very similar (Table 1). The nose was the site most frequently found to yield staphylococci (40 to 44%), though in Williams' series the rate for the back of the wrist was not very different (96). About 8 to 22% of the subjects yielded staphylococci from other skin areas. It has usually been found that the numbers of staphylococcal colonies on cultures from the nose are far greater than the numbers from skin swabs, and it is generally accepted that the nose is, in most

[1] This review originated in an Almroth Wright Lecture delivered at the Wright-Fleming Institute in May 1961.

carriers, the principal site of multiplication of the cocci. It is therefore most convenient to discuss nasal carriage in some detail first.

Nasal Carriage

Location of carriage within the nose. The common practice in seeking nasal carriers is to swab the skinlike area 1 to 2 cm inside the anterior nares, and it is to the results of such swabbing that most of this review refers. Moss et al. (63) swabbed the mucous membrane of the nasal fossa, taking care to avoid contamination of the swab from the nasal vestibule, and found staphylococci in only 32% of their 34 subjects, compared with 76% when the swab was taken from the vestibule alone. Similar results were obtained by Jacobs et al. (44). On the other hand, Stratford et al. (86) obtained a carrier rate of 51% (of 103 subjects) with "deep" swabs passed through the vestibule into the anterior part of the fossa compared with a rate of only 34% for swabs from the vestibule alone. The deep swabs must, of course, have been contaminated from the vestibule so that these authors' results do not necessarily conflict with those of Moss et al. (63), but the relative frequency of carriage in the different parts of the nose requires further careful study.

Nothing seems to be known of the actual site of multiplication of the staphylococci in or on the epithelium of the nose. Ridley (70) pointed out that the nasal epithelium shares with the skin of the axilla and perineum the character of having apocrine sweat glands; histological sections show a wealth of glandular structures in which one can imagine that staphylococci may multiply, but whether it is in fact within the glands or on the epithelial surface that the cocci are to be found is not known. The structure of the nasal fossa is very different from that of the vestibule, being covered largely by mucus-secreting columnar epithelium.

Frequency of nasal carriage in different population groups. The nasal carrier rates recorded for various groups of "normal" adults are shown in Table 2. Of the 16 studies of normal individuals outside hospitals, 11 gave rates between 30 and 50%, as did 5 of 8 studies of patients on admission to hospital. Most of these investigations were made in Britain, the United States, or Australia, and, so far as these countries are concerned, there were no significant geographical differences. Of the five records of much lower rates, two (23, 74) were from studies in West Africa and Borneo, respectively, and might be thought to indicate that tropical people have a lower carrier rate; Rountree (74) suggested that her finding might be associated with lack of clothes, for the tribesmen examined in Borneo were clothed only in a few leaves. That this is not the whole explanation is indicated by the fact that two of the other low carrier rates were for food handlers in Italy (18) and colored food handlers in the United States (61); in the latter study, white food handlers sampled in the same way had a carrier rate of 38%. One cannot generalize from these few reports of low rates, for the carrier rate is certainly in part a reflection of the bacteriological methods used; but at least it seems clear that carriage of *S. aureus* in the nose is not a phenomenon peculiar to the "advanced" communities, even though such communities may generally have higher rates than do less advanced. In contrast, children from remote Lapp communities were found by Laurell and Mellbin (47) to have carrier rates of 50 to 60%. And indeed *S. aureus* nasal carriage is common in monkeys, guinea pigs, and dogs (62, 76).

The staphylococcal carrier state of a sample of young men entering the Royal Air Force from homes in all areas of Britain was reported by McDonald et al. (51). The carrier rate among the men from homes in rural areas (35%) was slightly lower than that in men from urban areas (40%); a trivial difference in the same direction has been

TABLE 1. *Carriage on various skin sites*

Site	Percentage yielding *Staphylococcus aureus**		
	Williams, 1946 (96)	Martin and Whitehead, 1949 (56)	Ridley, 1959 (70)
Nose	44	40	42
Back of neck	10	—	—
Axilla	8	—	8
Forearm	20	—	—
Hand	40	14	—
Chest	12	18	—
Abdomen	16	14	16
Back	12	4	—
Perineum	—	—	22
Thigh	16	—	15
Leg and ankle	16	4	—

* The number of patients in each study was 50.

TABLE 2. *Nasal carrier rates in different population groups*

Carrier rate	No. of subjects and reference no. for reports giving specified carrier rates in				
	Normal adults outside hospital	Patients on admission to hospital	Patients in hospital more than 2 weeks	Nurses in hospital	Patients with sepsis
%					
0–10	167 (80)				
11–20	698 (18), 159 (61), 23 (74)				
21–30	150 (23)	113 (9), 833 (35), 3,056 (68)		65 (48)	
31–40	? (34), 101 (52), 50 (56), 1,165 (59), 418 (61), 100 (84)	501 (13), 125 (94), 602 (100)			2,138 (45)
41–50	520 (28), 217 (36), 3,720 (51), 800 (77), 50 (96)	536 (58), 349 (81)	158 (30)	222 (36)	82 (4), 120 (24)
51–60			543 (58), 221 (100)	30 (7), 49 (43), 590 (93)	10 (33)
61–70			197 (26)	104 (75), 96 (82)	
71–80					170 (53)

found among patients attending general practitioners (59).

There seem to be very few studies in which the carrier rates for men and women were compared; one recent survey of patients attending their family doctors (59) revealed no difference. In Britain, there does not appear to be any consistent seasonal trend in carrier rates. Johnson et al. (45) observed a lower rate in northern Australia than in the southern part of the continent. There has not been any notable change in total carrier rates over the last 20 years (64).

Changes in carrier rate with age. The highest carrier rates are seen in newborn infants, almost all of whom may acquire staphylococci within a few days of birth (see below). Thereafter, the nasal carrier rate declines so that children between 6 months and 2 years of age commonly have rates of around 20% (17, 39, 79). By the age of 5 to 6 years, "adult" carrier rates are observed. There is some evidence that the rates tend to be especially high in the age group from 10 to 20 years (59; Noble, *unpublished data*) and to decline gradually with age from then on.

Carriage by hospital patients and personnel. The striking factor in Table 2 is, however, the higher carrier rates recorded for hospital patients, hospital personnel, and patients with sepsis, using the term "sepsis" to cover any clinically manifest staphylococcal infection. Consideration of the last group may be deferred to a later section, but the increase in carriage associated with hospitalization is worth further discussion.

Several groups have observed a steady rise after hospitalization (e.g., 37, 100), with the rise largely accounted for by the acquisition of antibiotic-resistant strains.

In our own study, many of the patients who acquired resistant strains were not themselves treated with antibiotics. In other studies, the situation was different. Knight et al. (46) found that the change to resistant strains was much more rapid in patients treated with antibiotics, and Burke and Corrigan (8) observed no change in carrier rate during hospital stay. It is possible that these differences stem from the different colonizing capacities of the staphylococci in the hospitals studied, but they may also reflect differences in hospital ward structure or management between Britain and the United States, and it would certainly be valuable to make a formal comparison of acquisition of nasal staphylococci by patients nursed in wards of varying sizes. That the acquisition is not simply a result of widespread antibiotic treatment is shown by the carrier rate of 58% observed by Miles et al. (58)

in ward studies in Birmingham, England, in 1942–1943.

Moreover, there are several studies showing that nurses working in hospital wards have even higher carrier rates than do the patients (Table 2). There is no obvious explanation for the one reported low rate (48). Most of the more detailed studies have, however, been concerned with the change in the proportion of the antibiotic-resistant staphylococci carried, and some of the studies show a picture very similar to that observed with patients (e.g., 75).

In contrast, there are very few studies of changes in carrier state resulting from other forms of aggregation, though observation of recruits entering the Royal Air Force (60) revealed no evidence that this led to an increased rate.

It seems likely that the hospital may be to some extent peculiar in the ease with which it engenders staphylococcal carriage, perhaps because of the extent to which its occupants are inhaling dust from each others' bedclothes and the frequency with which these are contaminated with staphylococci. Our own experience has been that in surgical wards, at least, patients acquire staphylococci from other patients rather than from the hospital personnel (100, 102).

Acquisition by newborn infants. By far the most dramatic example of acquisition of staphylococci is in the newborn infant. Of the many published studies, that of Simpson et al. (83) may be taken as typical; by the fourth day of life, 60% of the infants had become nasal carriers, and the rate rose to 80% by the tenth day. Skin carriage, especially of the umbilical stump, appeared to precede nasal carriage. Very similar rates of acquisition were recorded by Hurst (39, 42) and by Cook et al. (15) who found, as others also have done, that 100% of the babies became carriers by about the tenth day of life. In a more recent study (98), a somewhat lower rate was observed. Infants examined on discharge from hospital on the fourth or fifth day of life also tend to have lower carrier rates (e.g., 42); this may account for the generally lower rates recorded for American hospitals.

This rapidity of colonization of the newborn is probably a characteristic of the infant rather than of the hospital environment. There are few comparable studies of infants born at home but, though acquisition may be slower than by hospital-born babies, the carrier rate reached by 2 to 4 weeks of age is not very different (Table 3).

TABLE 3. *Nose carrier rates at the age of 10 to 30 days*

Reference	Infants born	
	At home	In hospital
	%	%
Hurst, 1957 (39, 40)	72	100
Ludlam, 1953 (50)	59	78
Williams, 1961 (98)	59	65

Despite the close contact that the infant has with his mother, it has been a general finding that the babies do not very often acquire their mothers' staphylococci. Thus, of the 128 babies swabbed on discharge from hospital by Barber et al. (3), only 25 (20%) carried the type that their mother had had on admission to hospital. In another survey (98), only 10% of 502 babies had staphylococci of the same phage type as their mother on discharge from the hospital; the proportion was higher (17%) for babies of the same age born at home. Anderson et al. (1), in a hospital where only 36% of the babies yielded staphylococci on discharge, estimated that 35% of the carriers (i.e., about 13% of all babies) acquired their mothers' strains.

Presumably, most babies acquire their staphylococci from nurses (66), from other babies in the ward, or from other people in the home environment.

It seems that some skin area is often colonized before the nose (42, 83), and prevention of skin colonization by antiseptics probably delays the acquisition of staphylococci in the nose (25*a*, 83).

Persistence of nasal carriage. The relation of the carrier state soon after birth to that in later childhood or adolescence has not been properly worked out. Such records as there are indicate that, during the first year of life, children lose their nasal staphylococci so that the carrier rate in children 1 to 2 years old may be as low as 20% (e.g., 79); thereafter, the nasal carrier rate rises, reaching "adult" levels by the fourth or fifth year of age. Throat carriage may not decline to the same extent (see below).

Several studies have shown that the frequency of carriage of penicillin-resistant strains by children born in a hospital decreases with increasing age (41, 50, 79), and this has been interpreted as meaning that the staphylococci acquired in hospital at birth are lost over the next few years and replaced by new strains from the environ-

TABLE 4. *Persistence of staphylococcal carriage*

Reference	No. of subjects	Percentage carrying			
		Persistently	Intermittently	Occasionally	Never
Miles et al., 1944 (58)	27	20	70	—†	10
Bergqvist, 1950 (5)	81	33	28	—	38
Gould and McKillop, 1954 (28)	520	24	15	42	20
Rippon and Vogelsang, 1956 (71)	67*	24	59	—	16
Duncan et al., 1957 (20)	51	16	43	35	6

* Refers to children.

† Intermittent and occasional carriage was not distinguished in these reports.

ment. But, since all the studies have been retrospective, in that children born over a period of years were examined simultaneously, rather than prospective, with the observation of a single group of children, we cannot be certain that the result does not merely reflect difference in the strains acquired by the infants at the time of birth.

All the carrier rates discussed so far have been cross-sectional rates, i.e., the proportion of people found to be carriers at a single examination. In considering acquisition of staphylococci, it is interesting to inquire how persistently the staphylococcus may be carried in an individual's nose. There appear to be three main classes of carriers: the persistent carriers, the persistent noncarriers, and the intermittent carriers (Table 4). The last group may be further subdivided by separating off the "occasional" carriers, who yield isolated positive cultures from time to time. Some 10 to 20% of normal adults seem practically never to yield staphylococci from the nose, even on repeated swabbing; a further 10 to 20% yield staphylococci, usually in large numbers, at all examinations. Such people can harbor a single phage type of staphylococcus for very long periods, even up to 7 years in one of Roodyn's (73) patients. The intermittent carriers commonly carry staphylococci for periods of a few weeks at a time and are then free from staphylococci for comparable periods. They often carry different phage types in successive periods of carriage, which suggests that it is in fact the carriage of the staphylococci that is intermittent and not the ease of recovery of the staphylococcus from a persistent carrier (27); similarly, persistent carriers of a single type do occasionally yield negative cultures.

To some extent, apparent differences in persistence doubtless reflect variations in the numbers of cocci harbored in the nose (95); carriers with few organisms in the nose will, through inevitable deficiencies in the swabbing technique, appear from time to time to be noncarriers. Unpublished investigations of my own showed that preliminary enrichment in broth made little difference in the number of patients found to carry staphylococci in the nose, but did considerably increase the number recognized as skin carriers.

In the ordinary way, it seems that perhaps 10% of nasal carriers harbor two different phage types of staphylococci in the nose simultaneously (e.g., 75), though the proportion may be much higher than this in infants born in hospitals (39). We have records of several patients admitted to hospital wards as carriers, who acquired a new strain in the ward, and who subsequently lost the latter strain and reverted to carriage of their original strain. Although it is possible that this represents recolonization from clothing and the like, it is tempting to think that the original strain has persisted undetected throughout. The same is true of patients in whom carriage appears to be eliminated by antibiotic treatment, but who revert to carriage of their original staphylococcus when treatment ceases.

Practically nothing is known of the factors that make one person liable to carry staphylococci repeatedly while another is practically never a carrier, though Jacobs et al. (44) report that 20 nurses with minor deformities of the nose had a higher carrier rate (65%) than 55 nurses with no such abnormality (29%). There have been several speculations on the possible importance of humoral factors in determining carriage, but no experimental results seem to have been reported.

There are, on the other hand, some indications of differences between staphylococci that are

carried persistently and those that are not. When a group of recruits were examined on two occasions separated by 8 weeks, the proportion showing a change in the strain carried was greater for those initially carrying resistant strains than for those carrying sensitive strains (60). There was also a suggestion that the penicillin-resistant strains were less easily able to establish themselves in the noses of the infants studied by Williams (98); 58% of the babies with a resistant staphylococcus at the age of 2 weeks had changed their strain by the eighth week of life, compared with 49% of those who initially had a sensitive strain. There is also a suggestion that staphylococci of phage group I are more liable to persist in nurses' noses than those of group III (88).

Perhaps it is the relative inability of the resistant strains to establish themselves in the nose that leads to their gradual disappearance from the noses of patients after discharge from hospital, as has been recorded for adult patients (19; 26; Noble, *in preparation*) and infants (39, 50). In the case of adults, however, the situation is certainly complicated by the fact that the penicillin-resistant strains carried had usually been acquired during the patient's stay in hospital, and the easy loss might have been related to the recent acquisition.

Rountree and Barbour (75) were the first to point out that carriage of one coagulase-positive staphylococcus in the nose appears to act as some protection against the acquisition of another strain from the hospital environment. The observation was confirmed by Williams et al. (100).

Throat Carriage

The ease with which *S. aureus* can be isolated from the nose seems to have deflected interest from its presence in the tonsillar region, and there are very few published studies of throat carriage. Those that exist show a curious discrepancy (Table 5). Two groups of workers, one in the United States and one in England, report carrier rates of 4 and 7%, while three different studies from Scandinavia report very much higher rates. The differences may result from variations in technique or from differences in the populations. Campbell (11) noted a high staphylococcus throat carrier rate in patients with glandular fever.

In a small group of infants, Hurst (39) noted that, though the frequency of nasal carriage declined over the first year of life, 50 to 60% of the babies remained throat carriers. This excess of throat over nose carriers in infants 6 to 12 months of age has not been confirmed in other studies (6, 79).

TABLE 5. *Throat carriage in healthy adults*

Reference	Percentage of carriers
Campbell, 1948 (11)	4
Commission, 1949 (15)	7
Vogelsang, 1958 (92)	45
Packalen and Bergqvist, 1947 (65)	63
Vogelsang, 1951 (91)	64 60

Lapp children aged 7 to 14 years examined by Laurell and Mellbin (47) had throat carrier rates around 50%; in fact, the total carrier rate taking nose and throat into account was over 70%.

Skin Carriage

Although the nose is the carrier site from which staphylococci can most commonly be isolated, there are several skin areas with a carrier frequency that is not much less (see Table 1). It is, of course, rare for these skin sites to yield nearly as heavy a growth of staphylococci as is common in the nose but, when the total area of skin is considered, the staphylococcal load may be very considerable.

Different people vary in the number of skin sites from which staphylococci can be isolated. Thus, of the 50 students examined by Williams (96), 35 (70%) carried on 1 or more of 11 skin sites; only 13 carried on more than 2 different skin areas, but 2 had 9 or 10 different skin areas positive.

Some 60% or more of skin carriers of staphylococci also yield staphylococci from the nose at the same time (e.g., 25, 58). Repeated examination of a small number of skin carriers (96) suggested that the degree of association is really higher than this figure indicates because in some carriers the staphylococci can only be recovered from the nose intermittently.

In general, the staphylococci from the different skin areas on one person are found to be of one phage type, and this is usually the same as the type present in the nose (70, 96). Transient carriage of staphylococci different from that in the

nose also occurs, perhaps especially on exposed areas such as the hands.

There has been some discussion as to whether staphylococci actually multiply on the skin or whether those found are merely surviving after deposition from the real site of multiplication, usually thought to be the nose.

The local application of penicillin to the nose of staphylococcal carriers has been found to produce a great reduction in the number of *S. aureus* recovered from the skin (63), suggesting that the maintenance of the skin carrier state depends on continued recruitment from the nose. Some confirmation of this idea was given by the demonstration that protection of the skin of the forearm from external contamination, as by a nylon film, was followed by disappearance of the staphylococci from the protected area (69).

On the other hand, staphylococci have been shown to multiply on perineal skin; a heavy carrier who freed the skin of his perineum by washing and who then donned clean clothes was found to yield very large numbers of staphylococci from the cleaned skin area within 24 hr (32). Contamination from feces was excluded as a cause of this recolonization.

Possibly these different conclusions derive from the different techniques employed; however, it is also possible that the skin of the perineum differs from that of the forearm in its structure, e.g., in the numbers of apocrine glands (70) or in the nature of its secretions.

It has often been suggested that hand carriers are of two classes: those in whom the cocci are carried superficially and those in whom they are living in the depths of the skin glands. These "deep carriers" were thought to be recognizable by having the subjects disinfect the skin and then to put on sterile rubber gloves; subsequent sweating liberated the "deep" cocci, which could be demonstrated by taking press plates from the interior of the gloves. Certainly it is common to find that the bacterial colonies on such press plates are clustered, as might be expected if they arose from the discharge of a single gland.

An early attempt was also made to discover the actual site of multiplication of bacteria in the skin by histological examination of skin fragments that had been incubated for a few hours to allow growth of bacteria *in situ* (49). Bacterial "colonies" were visible in sebaceous glands but not in sweat glands; however, the techniques available at the time did not permit precise identification of the cocci seen. A similar distribution of skin bacteria was inferred by Evans et al. (22).

It thus seems very likely that the *S. aureus* found on normal skin fall into both of Price's (67) categories. Some of them are superficial transients being repeatedly replenished from the nose or some other site; others colonize the depth of the skin and multiply there and so contribute, for a time at least, to the permanent resident flora.

TABLE 6. *Intestinal carriage of staphylococci in patients on admission to hospital*

Reference	No. of patients	Percentage with *Staphylococcus aureus* in feces	Comment
Buttiaux and Pierret, 1949 (10)	83	56 rising to 81	Infants 1–10 days old
	22	100	Infants 2–6 months
	32	50	Infants 6–12 months
	277	18	Adults
Brodie et al., 1956 (7)	127	17	Rise to 38% during hospitalization
Matthias et al., 1957 (57)	196	23	Adults
Hofstad and Wormnes, 1961 (38)	167	21	Rise to 44% with antibiotic treatments
Grün, 1958 (29)	?	31	

Intestinal Carriage

Most studies of the frequency of staphylococci in the intestinal contents have been made on hospital patients; the results of a number of studies are shown in Table 6. Because of the large numbers of other bacteria, the frequency of staphylococci found in fecal samples must be especially affected by the variations in technique, but a rate of 20 to 30% for a single sample is clearly normal.

What little evidence there is suggests that newborn infants acquire staphylococci in their intestines very early in life and doubtless in

parallel with their nasal acquisition (42), though it has been claimed, without definite proof, that the mothers' milk may be the usual source of infection (10).

Among adults, nasal carriers have been found to yield staphylococci from their feces more often than noncarriers (57); the phage type of the fecal strain was the same as that of the nasal strain in 22 of 35 patients, and a further 5 yielded untypable strains from both sites.

HARMFUL CARRIAGE

Phage Types of Staphylococci from Carriers and Lesions

The preceding sections have reviewed the known facts on the frequency of healthy carriage of *S. aureus*. The biggest question posed by these facts is: how much does it matter? On the face of it, it is a remarkable phenomenon that so many people should normally harbor a microbe with such considerable powers of producing disease as the staphylococcus. Certainly none of the other pathogenic bacteria is carried in such wide distribution over such a large proportion of normal individuals.

One explanation for this apparent anomaly might be that the bacteriologist is mistaken in classing all the coagulase-positive staphylococci, from carrier sites and from lesions, into one species. Perhaps the staphylococci from the nose are really different from the lesion staphylococci. In a statistical sense, this idea has some truth, as shown by analysis of the phage types of some 8,000 strains of staphylococci from various sites examined at the Staphylococcus Reference Laboratory, Colindale, London (99). The salient facts are abstracted in Table 7. A few types, such as 52/52A/80, were found with similar frequency in healthy people, in sporadic septic lesions occurring outside hospital, and in cases of hospital infection. Other types, such as 52 and 3B, were distinctly more common in healthy carriers than in other sources. Yet others (e.g., 52A, 3C/55/71, and 42E) were more common in sporadic lesions than in other sources. And lastly, there are the now notorious "epidemic" types such as 80 (=80/81) and in Britain 47/53/75/77, 83A, etc., which in our experience were very rarely found in healthy people away from hospitals. [It should be noted that in other countries, e.g., Australia, carriage of type 80 staphylococci by healthy people seems to be more common (45).] The six types responsible for 42.7% of all the cases of sporadic sepsis made up only 15.9% of the nasal carrier strains. And seven types, responsible for 39.1% of the cases of hospital infection and all different from those common as causes of sporadic sepsis, constituted less than 10% of the carrier strains.

Thus, although practically all the phage types

TABLE 7. *Percentage type distribution of staphylococci from different sources, based on Williams and Jevons (99)*

Phage group	Phage type	Healthy nasal carriers (recruits)	Septic lesions	
			Outside hospital	Inside hospital
I	29	5.3	2.8	2.5
	52	*5.2**	2.2	0.8
	52A	1.5	*8.1*	3.1
	52A/79	4.2	*10.0*	3.7
	80†	0.6	3.1	*10.5*
	52/52A/80; 52/80†	4.2	5.2	7.1
Total		29.0	38.0	35.3
II	3C/55/71	2.5	*10.0*	2.8
	3B	*2.0*	0.8	0.1
	55/71	2.4	*4.4*	1.8
Total		24.8	31.3	11.1
III	6/7/47/53/54/75, etc.	1.7	0.6	*5.8*
	42E	1.1	*5.0*	1.9
	47/53/75/77, etc.	0.6	0.3	*4.3*
	75/77	—	—	*2.1*
	77	1.0	0.8	*3.6*
Total		14.9	14.4	41.4‡
No. of strains		710	360	1,311

* Percentages in italics are more than twice the mean of the percentages for the same type in the other two columns.

† Most strains in these groups were probably also lysed by phage 81.

‡ Of the group III strains from hospitals, 5.7% were type 83A; although phage 83A was not used for the whole survey, it seems certain that the type was constituted much less than 1% of normal carrier strains.

of staphylococci have been found at some time or another to produce either a carrier state or a septic lesion, there are obvious differences in the type distribution from different sources. Doubtless the same would be true if it were possible to measure severity of sepsis. These studies at least provide a basis for thinking that the frequency of fully pathogenic strains in the population may be a good deal less than would be implied by the total frequency of coagulase-positive staphylococci.

In passing, it may be noted that there are, of course, other known differences between staphylococci from lesions and those from carrier sites in production of toxins and other extracellular products. It is, however, in most cases very difficult to judge whether these differences might not simply reflect the past history of the strain rather than indicate its potential. What is needed is the prospective experiment to see whether the less toxigenic strains, given the opportunity, are less able to produce disease than the more toxigenic. There is some indication that this may be so (101), but there is need for more extensive studies.

The phage-type distributions suggest that some caution is needed before we conclude that the nose is the reservoir from which the infection of wound sepsis, or skin sepsis, is derived. But though the distributions differ, it is still true that all the staphylococcal types found in septic lesions are also found in the noses of some healthy carriers, though these may be outnumbered by carriers of types that rarely produce disease.

In considering how dangerous the carrier state may be, we need then to consider, first, the possible danger to the carrier himself and, second, the danger to others.

Self-Infection in Carriers

When nonhospitalized patients with septic lesions are examined, most of them are found to be nasal carriers of staphylococci, and there is a striking consonance between the type found in the nose and that found in the lesion. This consonance is greatest for patients with recurrent skin sepsis (Table 8). This fact, and the observation that patients with recurrent sepsis commonly harbor the same phage type of staphylococcus in their noses over long periods whether or not they have a lesion (e.g., 73), is a strong indication that the nose is the reservoir from which the recurrent infections are derived. Moreover, there are now a number of investigations showing that recurrent skin sepsis can often be cured by elimination of the nasal staphylococci (e.g., 89).

TABLE 8. *Nasal staphylococci in patients with septic lesions outside hospital*

Reference	Type of lesion	Patients with same type in nose
		%
Galbraith, 1960 (24)	Skin sepsis	30
Ruys et al., 1958 (78)	Boils	32
Roodyn, 1954 (72)	Boils	37
Gould and Cruikshank, 1957 (27)	Skin sepsis	74
Valentine and Hall-Smith, 1952 (90)	Boils and styes	76
Roodyn, 1954 (72)	Styes	77

Another indication of the risk attached to the carrier state comes from prospective studies. In a study of Royal Air Force recruits, Miller et al. (60) observed 3,512 men for 8 weeks after an initial nasal swabbing; 9.6% of those who were carriers reported a septic skin lesion within the 8-week period compared with 5.6% of those who were noncarriers. A prospective study in coal miners (2) showed 44% of 82 carriers to develop skin sepsis ("beat disease") compared with 20% of noncarriers.

The same question has been studied in surgical patients (Table 9). Two studies of our own (35, 100) in which the patients had repeated nasal swabs taken during their stay in hospital showed that those who were or became nasal carriers had a higher incidence of postoperative sepsis than those who remained noncarriers. (Though not illustrated in Table 9, they also had a greater incidence of other staphylococcal infections.) This experience is very similar to that of Colbeck et al. (13) and of Weinstein (94). It is not, however, a universal experience, for Bassett et al. (4*a*), in extensive investigations, could find no such difference. It is not possible to account for these variations. To some extent, they certainly derive from differences in the methods used in the investigations, but other factors that must play a part include the locally important mode of transmission of infection and the prevalent types of staphylococci.

It may, nevertheless, be worth examining in

TABLE 9. *Staphylococcal postoperative wound sepsis in nasal carriers and noncarriers*

Reference	Wound sepsis in		Percentage of sepsis due to nasal staphylococcus
	Carriers	Noncarriers	
Nose swabbed only on admission to hospital			
Colbeck et al., 1959 (13)	14.4	2.1	75
Weinstein, 1959 (94)	14.2	1.5	(High)
Public Health Lab. Service, 1960 (68)	8.9	7.1	33
Nose swabbed repeatedly			
Williams et al., 1959 (100)	7.1	2.0	53
Henderson and Williams, 1961 (35)	7.8	1.1	47
Bassett et al. (4*a*)	5.6	7.6	45
McNeill et al., 1961 (54)	16.5	5.6	89

rather more detail the results obtained in our study at St. Bartholomew's Hospital, London (100).

The postoperative sepsis rate in the patients who were never nasal carriers was 2%. In those who carried at some time during their stay, the rate was 7%. In parentheses we can note that the rate on the patients who were carriers on admission to the ward was only 4%; it was the patients who acquired hospital staphylococci who fared worst. Altogether 34 patients developed sepsis; 18 of them yielded staphylococci of the same type in nose and lesion, and in only 3 cases was the nasal staphylococcus first isolated after the development of the wound sepsis. Of the 18 patients who had the same staphylococcus type in nose and wound, 11 acquired their staphylococcus in the ward after admission. Moreover, when we considered the different phage types and arbitrarily classified the types causing more than one septic lesion as locally "virulent," we found that the sepsis rate among the patients who became carriers of virulent types was 35%, compared with 5% for the other types. These results were, in general, confirmed by a further study in the same hospital (102).

A similar difference was seen in the survey carried out by the Public Health Laboratory Service (68); in this, the patients were swabbed once only, almost always on admission to hospital. Over-all, there was little excess of sepsis among the carriers (8.9 against 7.1%), but carriers of well-known epidemic types of staphylococci had a sepsis rate of 15%, and all but one of these wound infections was with the nasal type of staphylococcus.

The simplest explanation of these findings is that the patients have or acquire the staphylococcus in their noses and, when opportunity arises and if the staphylococcus has the capability, subsequently infect their own wounds, probably by prior contamination of their skin. But there are other possibilities. Infection of the nose from the lesion must occur but does not seem to be the general explanation of the association, because the nose is commonly shown to be infected before the lesion, in many cases even before the surgical operation. A possibility that is much more difficult to exclude is that both nose and lesion are infected independently, from a common external source. When a single type of staphylococcus is producing most of the infections in a ward, as in the study of Henderson and Williams (35), this possibility is a very real one and is very difficult to exclude. In the wards reported by Williams et al. (100), the number of different types responsible for the infections seemed to make it unlikely that we should have seen the same type in both nose and lesion so frequently by chance alone. But there is certainly scope for much more detailed investigation of individual patients.

Another possibility, that some patients simply have a special tendency to become infected with staphylococci, would hardly explain the concordance of types in nose and lesion; in any case, nasal carriers and noncarriers had, in our experience, an equal risk of acquiring infection with staphylococci different in type from those in their noses.

The higher sepsis rate for carriers has also been noted among newborn babies (55).

From all these studies, it seems quite certain that, at least in some circumstances, nasal carriers of staphylococci are more likely than noncarriers to suffer from septic lesions and that this may well be simply a result of their carrier state. It seems probable that self-infection of this sort is not more common, partly at least, because many strains of staphylococci carried in the nose are relatively incompetent to produce disease.

Cross-Infection from Carriers

There are many records of healthy carriers who have conveyed their staphylococci to other people, with resultant sepsis. The simplest example is the infant who acquires his staphylococcus in hospital, takes it home, and at some convenient later date inoculates it into his mother's breast to produce a breast abscess (e.g., 104). The mechanisms of such infection seem simple enough; the problem is why it happens just when it does.

There are also several records of outbreaks of infection in surgical and maternity departments in which a healthy carrier seemed to have been responsible for spreading infection among the patients (66, 97, 103), though it has to be admitted that the evidence in several of the published reports is not very convincing.

Analysis of an extensive study in some surgical wards (102) enables us to give a more quantitative measure of the risk of spread from carriers. This analysis was confined to those strains of *S. aureus* that manifested some ability to spread by colonizing at least two patients. On the average, a single carrier present in the ward gave rise to carriage or infection of one new patient every 14 days; when there were two carriers of a particular staphylococcus in the ward, a new infection arose about every 10 days; with three or more carriers, the rate was one every 7 days. The exact figures would be expected to vary greatly from place to place, as well as with the different phage types of staphylococcus, but this example probably affords an indication of the order of magnitude of the communicability from nasal carriers. In this ward, septic lesions generated hardly any more spread than carriers.

Apart from differences in the staphylococci, the topic that has been most discussed is the possible existence of carriers with different abilities to disperse. With the hemolytic streptococcus, for example, the recognition of "dangerous carriers" contributed enormously to our understanding of the mode of spread. There are certainly striking differences in the ability of different staphylococcal carriers to disperse the organisms they carry (32, 64*a*, 95*a*). Hare and his colleagues were able to distinguish a small number of healthy carriers whose clothing yielded far greater numbers than the average and concluded that, in part at least, this could be correlated with perineal carriage. Those with heavy contamination of clothing distribute large numbers of staphylococci into the air, and the numbers may be as large as those distributed by patients with septic lesions.

Surveys in which the air of surgical wards was regularly examined for staphylococci have given similar indications. Thus, in an 8-month period, we observed a series of nine "broadcasts" of staphylococci (82), and several of these could be attributed to dispersal from single carriers with no staphylococcal disease. Subsequent studies in the same ward (Noble, 64*a*) revealed eight instances of carriers who were able to produce widespread contamination of air and fabrics, leading to the development of the carrier state in other patients. Noble has shown that the main source of the airborne staphylococci is the patient's bedclothes; he did not undertake routine swabbing of the perineum, and we still do not know what proportion of active dispersers are perineal carriers, nor how frequently perineal carriers are active dispersers. Our own studies, in contrast to those of Burke and Corrigan (8), did not yield convincing evidence that septic lesions were more, or indeed often as, effective in dispersal as the healthy carrier state. White (95*a*) found that the degree of air and bed contamination around carriers is correlated with the number of staphylococci found in nasal cultures, though this conflicts with the earlier observation of Hare and Ridley (32).

Similar studies in infants, carried out by Eichenwald et al. (21), have suggested that infants who are healthy carriers and who then acquire some virus infections may thereby be converted into very effective dispersers of their staphylococci.

The question remains, however, whether the active dispersers detected by air or clothing sampling are those who are responsible for epidemics of infection. In the maternity nurseries studied by Eichenwald and his colleagues (21), this appeared to be the case, but in our own studies in surgical wards it has been striking how few of our active dispersers have given rise to clinically manifest infection in other patients. It so happens that only one of the eight dispersers studied by Noble carried a recognizably "virulent" strain of staphylococcus.

Conclusion

Clearly, healthy carriers can be harmful. It is perhaps worth commenting on the curiosity of the situation. The staphylococcus gives every appearance of being a highly efficient parasite of the nasal epithelium and, to some extent, of the skin of man (and of some animals), which is easily transmitted from man to man and which rarely causes harm in its primary sites of colonization. The excursions of the staphylococcus into disease production seem to be aberrant activities outside the main stream of its existence. Smith (85) wrote 30 years ago that aberrant movements are the most important factors in parasitism, that aberrancy is the adventurous element in the life of the parasite, which leads either to death or to new conquests. We may speculate whether, by producing disease, the staphylococcus does its race any good (in the sense of enabling it to make new conquests) and, if not, what part the considerable armamentarium of seemingly toxic excretions plays in helping the staphylococcus in its normal commensal existence. Though there are undoubtedly some sorts of septic lesion that generate spreading infection (31, 87), many lesions seem no more efficient in this respect than carrier sites. The factors, in the host or in the staphylococcus, that lead to the establishment of the carrier state are quite unknown, and there is a clear need for further study of the biology of the staphylococcus, in particular to discover to what extent there may be varieties of staphylococci whose continued existence may, for some reason, be dependent on their producing disease, perhaps because they are less well adapted to the peaceful commensalism of the healthy carrier state.

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